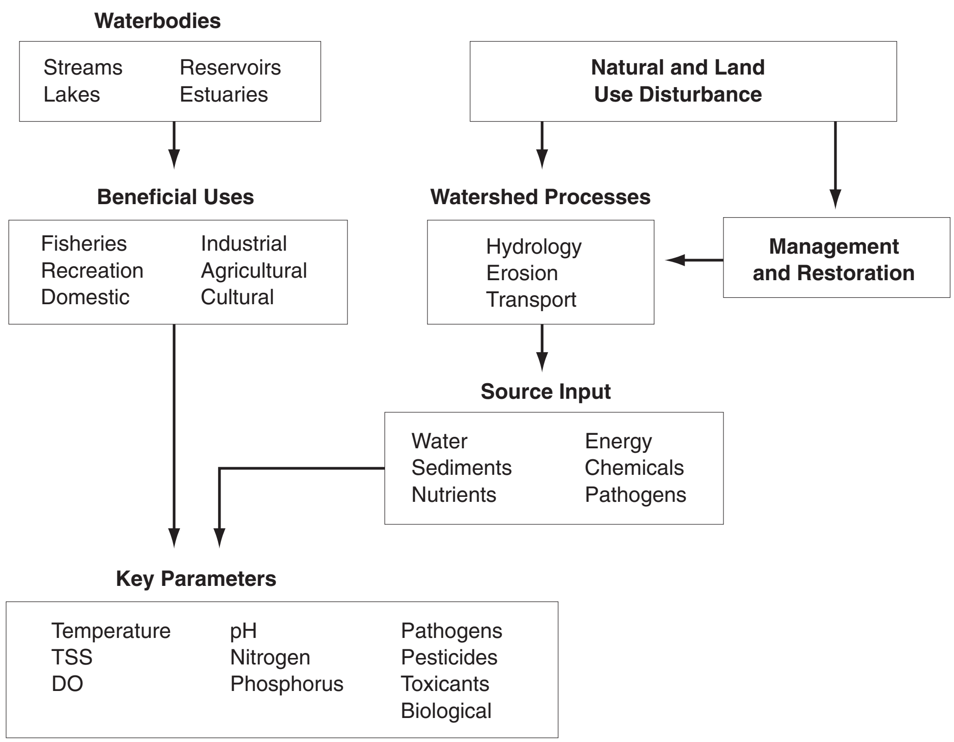
Water Quality

Background and Objectives

The goal of the Water Quality assessment is to evaluate the status of specific waterbodies as reflected by various water quality parameters related to the health of community resources (Figure 1). The evaluation process will not only aid in identifying existing water quality problems but will also identify the possible sources that may have caused the problems and suggest changes in management practices or restoration possibilities.

Figure 1. Water quality assessment



Regional Interagency Executive Committee (RIEC) and Intergovernmental Advisory Committee (IAC) (1995)

Level 1 Water Quality assessment is a screening process that characterizes the status of water quality in the watershed and identifies potential sources of impacts. The assessment can also identify which waterbodies are at risk and where more in-depth assessment is needed to address specific pollution problems.

Level 2 Water Quality assessment can be conducted for stream segments or waterbodies that have been identified as impaired by the Level 1 assessment or that are on the State

303(d) list. Level 2 assessment provides detailed examination of pollution sources and a complete description of water quality problems. Targeted stream sampling plans may be developed to pinpoint pollution sources and provide quantitative information on the degree of impact from a specific source. Level 2 assessment is also helpful when a higher level of certainty is required, such as when developing TMDLs or restoration strategies.

Water Quality Module Reference Table

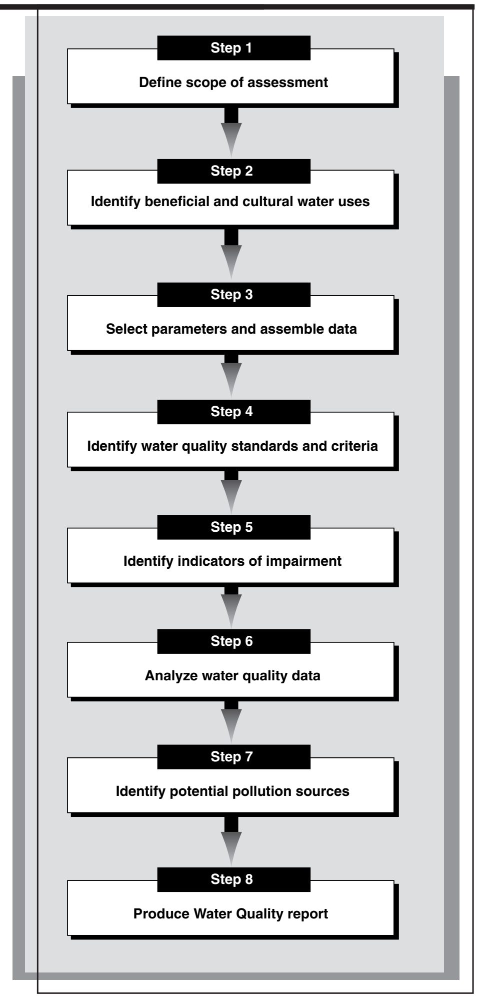
Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
WQ1: What are the beneficial uses of water resources?	• State, tribal, and local documentation	• Survey community members • Interview government agencies	
WQ2: What water quality parameters have not met the standard and for what time period?	• 303d list • EPA, state, and tribal standards • Monitoring data • Additional information required for modeling	• Compare the available data to standards • Trend analysis	• Statistical analysis • Modeling • Additional monitoring • Toxicity test
WQ3: How much difference exists between current water quality and reference conditions?	• Map and other description of the reference conditions • 303d list • EPA, state, and tribal standards • Monitoring data	• Summarize and compare available data • Describe the reference conditions • Survey various users	• Field surveys • Monitoring • Stream classification
WQ4: What causes temperature impairment?	• 303d list • Change in water and land use • NPDES data • Weather data • Flow data • Aerial photos of riparian conditions • Stream characterizations	• Identify possible point and nonpoint sources • Identify diversions and new water uses • Identify land use change and any abnormal climate conditions	• Mixing and heat balance calculations • Computer simulations
WQ5: What causes fish consumption advisories?	• Water quality data, especially PCBs, metals, and organic compounds. • Reports of previous advisories • NPDES data • Fish tissue analysis results • Benthic sediments and pathogens data	• Identify possible point and nonpoint sources • Interview water users	• Toxicity analysis • Bioaccumulation analysis
WQ6: What causes fish kills?	• DO, temperature • Chemical spills, and mining activities • Fish species • Stream characteristics • Nutrient concentrations • Flow data • pH	• Compare water quality data to available standard for the fish species • Identify potential pollutant sources affecting fish survival	• Computer simulation for dynamics of DO, temperature, pH, and algae
WQ7: What causes excessive algae growth or eutrophication?	• NPDES data • 303d list • Land uses • Data on nitrogen and phosphorus concentrations • Temperature • Turbidity • Flow • Chorophyll-a • Solar radiation	• Examine data for excessive nutrient concentration and aquatic weeds • Identify potential nutrient sources	• Predict primary productivity • Computer simulations

Water Quality Module Reference Table (continued)

Critical Questions	Information Requirements	Level 1 Methods/Tools	Level 2 Methods/Tools
WQ8: What can cause beach or swimming area closures and other pathogen problems?	• Data from Health Department • Beach locations • Livestock facilities and septic systems • Flow data • Hydrological data • Pathogen attenuation rates	• Identify potential pathogen sources of agricultural and urban origin.	• Pathogen die- off and transport calculation • Computer simulations
WQ9: What conditions lead to excessive turbidity?	• Land use and soil type data • Urban construction sites • Road data • Agricultural practices • Wind data • Hydrological data • Watershed characteristics		• Erosion and sediment delivery models • WEPP, RUSLE and other computer simulation models
WQ10: What causes foul odors?	• NPDES data • Industrial facilities • Livestock production facilities • Water surface change • DO • Flow rate • Volatile compound	• Identify sources such as industrial processes, wetlands, wastewater treatment plants, failed septic systems	• Calculate volatilization rate • Identify odorous substances
WQ11: What adverse impacts on wetlands might have resulted from water quality impairments?	• Data on sediments, nutrients, and toxic chemicals • Water balance • Water temperature • Change in water salinity	• Mapping historical and existing wetland areas • Evaluate changes in vegetation sensitive to water quality	• Modeling and computer simulations • Additional water analysis for toxic substances
WQ12: What are the other possible major sources causing water quality problems?	• Acid mine drainage • Chemical spills • Irrigation return flows • Landfill sites • Connection to storm sewer • Leaking underground storage tanks • Atmospheric deposition • Acid rain • Groundwater • Monitoring data	• Identify locations of the potential sources	• Pathway analysis • Additional monitoring • Modeling and computer simulation • Examine land fill records • Check irrigation flow quality data

Background and Objectives

Step Chart



Data Requirements and Sources

Data requirements

The following is a brief list of the data required to begin the Water Quality assessment. Some of the maps and data may not be available for a given watershed or may not be necessary depending on the scope of water quality issues.

- USGS topographic map of the watershed (1:24,000 scale).
- GIS stream layer (if available).
- Copies of existing water quality data and reports.
- 305(b) list reports and inventories of state waterbodies.
- 303(d) list of state waterbodies not in compliance with the Water Pollution Control Act of 1972 (Clean Water Act [CWA]).
- NPDES permit compliance data for point source discharges.

Data sources

There are numerous sources of water quality data currently available, and access to the web has greatly facilitated the distribution of information (Tables 1 and 2). Water quality information may be accessed in different forms, such as raw data, databases, and reports. Reports and databases generally prove to be better sources than simple raw data. Reports offer the advantage that previous synthesis and analysis efforts have been made. Details on how the data were collected may also be provided. Most commercial databases are compiled based on the original data collected with QA/QC protocols. Although raw data may be available locally, it will most likely need to be processed before analysis.

Table 1. Internet sources for water quality information

Web site	Web address	Description
EPA Surf Your Watershed	http://www.epa.gov/surf2	• Location of watershed • Assessment of watershed health • State and tribal Unified Watershed Assessments and contacts • EPA regulated facilities and pollutant discharges • Links to community groups
EPA Unified Watershed Assessments	http://www.epa.gov/cleanwater/uwafinal/appc.html	• Links to and descriptions of federal programs for collecting water quality information
EPA and NRCS Clean Water Action Plan	http://www.epa.gov/cleanwater/links.html or http://www.nhq.nrcs.usda.gov/cleanwater/links.html	• Links to federal, state, and private sites with environmental data and other information
EPA STORET	http://www.epa.gov/owow/storet/	• Large national database of water quality information
USGS Water Resources Data	http://water.usgs.gov/data.html	• Links to water flow, water quality, and climate data
USGS National Water Quality Assessment Program	http://water.usgs.gov/nawqa/nawqa_home.html	• Describes the status and trends in the quality of the nation's groundwater and surface water resources
USGS National Mapping Program	http://mapping.usgs.gov/	• Contains topographic maps, spatial data, and remote sensing data
Association of State and Interstate Water Pollution Control Administrators	http://www.asiwpca.org	• Links to state water quality programs
NRCS National Resources Inventory	http://www.nhq.nrcs.usda.gov/NRI/	• Statistically-based sample of land use and natural resource conditions and trends on non-federal lands in the United States

Products

- Form WQ1. Summary of water quality conditions
- Map WQ1. Water quality impairments
- Water Quality report

Procedure

The objectives of the Water Quality assessment are as follows:

- To identify the beneficial and cultural uses of water resources.

Table 2. Local sources of water quality information

Data Source	Description
State 303(d) and 305(b) reports	• 303(d) reports list water quality impaired waterbodies and parameters exceeding standards. • 305(b) reports characterize general water quality conditions and programs to restore and protect waters.
Section 314 and 319 lists	• Section 314 lists indicate the water quality status of public lakes, including point and non-point source pollution problems. • Section 319 lists were created in 1989 and characterize water quality problems in coastal areas.
State and local soil conservation districts	• Expertise and information may be available on the effects of agricultural practices such as grazing, irrigation, and waste management.
State and tribal health departments	• Expertise and information may be available on drinking water, septic tanks, and community health.
University libraries	• Unpublished reports, dissertations, and theses may be available in science and engineering libraries.

- To summarize water quality parameters related to the resource uses.
- To assess the trends and status of important water quality parameters.
- To identify sources of water quality impacts.

Step 1. Define scope of assessment

Identify the key personnel and assign responsibilities for the Water Quality assessment team. Team members may be from within the lead tribal organization or may consist of external community members or experts.

A preliminary plan of action should be developed that succinctly defines the assessment objectives. The stream segments or sub-basins to be assessed, general time-frame for completion, anticipated data collection problems, and responsibilities for final products should all be discussed. Collecting, analyzing, and reporting water quality data that have very little or no impact on the Water Quality assessment can waste a significant amount of time.

Step 2. Identify beneficial and cultural water uses

Identify all legally defined beneficial uses and other potential beneficial uses (e.g., cultural) of the water resources within the watershed. The beneficial use of each stream segment

Table 3. Examples of beneficial uses and related water quality parameters

Beneficial use categories	Key pollutant parameters
Fish and wildlife	TSS Turbidity DO Toxic chemicals Temperature Bacteria
Agriculture	TSS Toxic chemicals
Public water supply	TSS Turbidity Toxic chemicals Bacteria
Navigation	Sediments
Industry	TSS Turbidity
Hydropower	Turbidity TSS/sediment yield
Recreation	Turbidity (aesthetics and safety) Bacteria

EPA (1994)

should be identified from the mouth of the mainstem upstream to the tributaries. A list of federally recognized beneficial uses is shown in Table 3. Beneficial uses should be listed in Form WQ1.

After determining the beneficial uses currently assigned to each stream segment in the watershed, the Water Quality assessment team can begin to discuss whether these designations make sense given the team's knowledge of the watershed. The key questions in Box 1 are a useful guide to ensure that all relevant issues are addressed during this step.

The CWA directed states to establish water quality standards related to the intended uses (or beneficial uses) of surface waters. Some states have completed beneficial use status and attainability assessments for various rivers. The beneficial uses outlined in the CWA do not include cultural or ceremonial water uses, but the CWA does allow flexibility in identifying new uses or biota categories. The analyst should coordinate with the Community Resources and Historical Conditions analysts to identify potential beneficial uses of cultural significance. Establishing new beneficial uses will often require supporting documentation of the following:

Community Resources
Historical Conditions

- Historical use.
- Locations of cultural significance.
- Cultural use protection standards.

Box 1. Key questions for beneficial use identification

- Where are the surface waters, lakes, ponds, estuaries, groundwater aquifers, wetlands, etc.?
- What are the current identified beneficial uses?
- What are the historical beneficial uses?
- What are the key parameters related to the beneficial uses?
- Were any of the beneficial use changes caused by water quality?

Step 3. Select parameters and assemble data

Select water quality parameters

Based on the identified beneficial and cultural uses, determine which water quality parameters will need to be evaluated. Tables 4 and 5 list parameters that typically need to be evaluated for a variety of beneficial uses; the importance of each parameter for each use is rated High, Moderate, or Low.

The parameters for which data are most commonly required are as follows:

- Temperature.
- Total suspended solids (TSS).
- Dissolved oxygen (DO).
- pH (acidity).
- Nutrients (e.g., nitrogen and phosphorus).
- Pathogens (e.g., fecal coliforms).
- Pesticides.
- Metals (e.g., cadmium, chromium, copper, lead, mercury, and zinc).
- Other toxic chemicals.
- Biological conditions.

More extensive definitions of these parameters can be found in introductory water quality texts. The relationships between parameters and community resources are briefly described in the following sections.

Temperature

Elevated stream temperatures can stress and cause behavioral changes in fish populations and other biota. Warmer water temperatures can change aquatic community assemblages, reduce growth rates, and increase disease.

Although land use impacts generally elevate stream temperatures, vegetation removal may cause cooler water temperatures during the winter. Cooler winter water temperatures may reduce growth of fish and can also cause the formation of anchor ice that smothers aquatic life in the stream substrate.

Temperature can also affect a number of other important water quality parameters. Gas solubility decreases with increasing temperature, resulting in generally lower DO

Table 4. Parameter selection for water quality assessment in relation to water uses

Variables	Background monitoring	Aquatic life and fisheries	Drinking water sources	Recreation and health	Irrigation	Livestock watering	Power generation	Iron and steel	Pulp and paper	Food processing	Petroleum
Temperature	H	H		L				H	L		
Color	M		M	M					L	M	
Odor			M	M						H	
Suspended Solids	H	H	H	H			M	M	L	M	H
Turbidity	L	M	M	M					M	M	
Conductivity	M	L	L		L						
Total dissolved solids		L	L		H	L	H	M	H	H	L
pH	H	M	L	L	M		H	M	M	H	H
DO	H	H	L		L		L	H	L		
Chlorophyll a	L	M	M	M							
Ammonia	L	H	L				L			L	
Nitrate/Nitrite	M	L	H			M				M	L
Phosphorus	M								L		
Total organic carbon	M		L	L							
Chemical oxygen demand	M	M					M				
Biochemical oxygen demand	H	H	M								
Sodium	L		L		H						
Potassium	L										
Calcium	L				L	L	H		L	L	H
Magnesium	M		L				L		L	L	H
Chloride	M		L		H		M	M	L	H	H
Sulphate	L		L			L	M	M	M	H	L
Fluoride			M		L	L					
Boron					M	L					
Cyanide		L	L								
Metals		M	H		L	L	L		L	M	
Arsenic/Selenium		M	M		L	L					
Oil and Hydrocarbons		L	M				L	L		L	H
Organic Solvents		L	H							L	
Phenols		L	M							L	
Pesticides		M	M							L	
Fecal Coliforms			H	H	H						
Total Coliforms			H	H	L						
Pathogens			H	H	L	M				H	

Chapman (1996)

Table 5. Parameter selection for water quality assessment in relation to additional water uses

Variables	Municipal wastewater	Urban runoff	Agriculture	Solid waste	Atmospheric transport	Textiles	Chemical pharmaceutical	Machine production
Temperature	L	L	M			L	L	L
Color	L	L	L	L		L	L	L
Odor	M	L	M			L	L	L
Suspended Solids	H	M	H	M		H	L	H
Turbidity								
Conductivity	M	M	M	H	H	H	L	H
Eh	L	L	L			L	L	L
pH	L	L	L	M	H	L	H	L
Dissolved Oxygen	H	H	H	H		H	H	L
Hardness	L	L	L		L	L	L	L
Ammonia	H	M	H	M		L	M	L
Nitrate/Nitrite	H	M	H	M	H	L	M	L
Phosphorus	H	M	H	L	L	L	M	L
Total organic carbon	L	L	L			L	M	L
Chemical oxygen demand	M	M	L	H		L	H	L
Biochemical oxygen demand	H	M	H	H		H	M	L
Sodium	M	M	M			L	L	
Potassium	L	L	L			L	L	
Calcium	L	L	L			L	L	L
Magnesium	L	L	L			L	L	
Chloride	H	M	H	M		H	M	L
Sulphate	L	L	L		H	L	M	L
Fluoride	L	L				L	M	
Boron			L			L	L	L
Cyanide						L	L	L
Metals	M	M	M	H	L	M	M	H
Arsenic/Selenium		L	H	L	L	L	L	L
Oil and Hydrocarbons	M	H		M		L	M	H
Organic Solvents	L	L		H		L	H	L
Phenols	L			M		L	H	
Pesticides		L	H	M	H		H	
Fecal Coliforms	H	M	M	H				
Total Coliforms	H							
Pathogens	H		M	H				

Chapman (1996)

concentrations and reaeration rates. With temperature increases, chemical and biochemical reaction rates typically increase markedly and mineral solubility increases. Most organisms have distinct temperature ranges within which they can reproduce and compete effectively.

Total suspended solids (TSS)

TSS are defined as the particles in the water column that are larger than 2 microns in diameter. In streams, the majority of TSS are fine sediments or algae. Laboratory procedures for measuring TSS involve time-consuming processes of filtering, drying, cooling, and weighing. Because TSS can be related to the turbidity of the water, turbidity is used in many cases to evaluate the concentration of fine particulate material suspended in the water column. Turbidity can be quickly measured by determining light transmission in water.

Sediment may directly affect fish by causing gill abrasion or fin rot. Sediment can indirectly impact aquatic biota by reducing habitat through blanketing of fish spawning and feeding areas, by eliminating sensitive food organisms, or by reducing sunlight penetration to aquatic plants, thereby impairing photosynthesis.

Suspended sediment also decreases recreational values, adds to the mechanical wear of water supply pumps and distribution systems, and adds to treatment costs for water supplies. Suspended sediment may also provide a mechanism for transport of pesticides or other toxic compounds.

Dissolved oxygen (DO)

DO is defined as the amount of oxygen dissolved in water. The presence of oxygen is of fundamental importance in maintaining aquatic life and the aesthetic quality of waters. Low DO concentrations may harm fish and aquatic biota. Fish tolerance of low DO levels varies by species, growth cycle, acclimation time, and temperature. Cold water fish (e.g., salmon and trout) require higher DO concentrations than do warm water fish and biota. The preferred DO level for trout is generally greater than 5 mg/L. Rough fish such as carp and catfish can survive at oxygen levels as low as 2 mg/L and also tolerate warmer water.

pH (acidity)

pH represents the concentration of hydrogen ions in water and thus indicates the acidity of the water. As water becomes more basic, pH increases; as water becomes more acidic, pH decreases. pH affects the reaction and equilibrium relationships of many chemicals. Many biological systems function only in relatively narrow pH ranges (typically 6.5 to 8.5). Fish and other aquatic species prefer a pH near neutral (7) but can withstand a pH in the range of about 6 to 8.5. Low pH in water inhibits enzymatic activity in aquatic organisms. The toxicity of many compounds can also be altered if the pH is changed. The solubility of many metals, as well as other compounds, is affected by pH, resulting in increased toxicity in the lower pH range.

Nutrients—phosphorus and nitrogen

Both phosphorus and nitrogen are essential nutrients for the growth of aquatic vegetation. Phosphorus is essential for the growth of algae and other aquatic organisms. Serious problems such as algae blooms and fish kills have resulted when excess phosphorus exists in the aquatic environment.

Nitrogen is a complex element that can exist in seven states of oxidation. From a water quality standpoint, the nitrogen-containing compounds that are of most interest are organic nitrogen, ammonia, nitrate, and nitrogen gas. Table 6 summarizes the generally reported forms of nitrogen.

Table 6. Summary of nitrogen forms

Total Nitrogen				
Total Inorganic			**Total Organic**	
		Total Kjeldahl Nitrogen (TKN)		
Nitrogen	Nitrate	Ammonia	Dissolved	Particulate
Readily available for aquatic plant growth			Must undergo microbial degradation to become available	

Nutrient enrichment of surface waters may cause excessive algae and aquatic plant growth. This creates large diurnal oxygen fluctuations due to excessive DO production during daylight hours followed by excessive consumption of oxygen (mainly through plant die-off) when photosynthesis is not occurring. Seasonal die-off of vegetation due to frost may also create large oxygen demands and suffocate fish and aquatic organisms. Physical impediments to fishing and boating and operation of water supply facilities can also be affected when vegetation becomes so overgrown that leaves and roots clog motors and intakes. Nitrate contaminants in drinking water significantly above the drinking water standard (10 mg/L) may cause methemoglobinemia (a blood disease) in infants and have forced closure of several water supplies. High ammonia concentrations in water are also toxic to fish and cause an odor problem.

Pathogens

Pathogenic bacteria, protozoa, and viruses include infectious agents and disease-producing organisms normally associated with human and animal wastes. Waterborne pathogens can be transmitted to humans or animals through drinking water supplies, direct contact recreation, or consumption of contaminated shellfish. Bacterial pathogens of concern include *V. cholerae*, *Salmonellae*, and *Shigella*. Pathogenic protozoan eggs and cysts have been linked to *Giardia lambia* and *Entamoeba histolytica* (amoebic dysentery). Viruses ingested from water can lead to diseases such as hepatitis (Thomann and Mueller 1987).

Detection methods for pathogenic bacteria are severely limited because of the difficulty in isolating a small number of cells. Consequently, in spite of problems establishing direct correlations, coliform groups can serve as indicators of pathogens. Fecal coliform bacteria behave similarly to common enteric pathogens, and a close relationship exists between the growth and survival of fecal coliform and both *Salmonella* and *Shigella*.

Relationships between the total coliform bacteria group and pathogens are not considered to be quantitative. Because of the occurrence and interference of nonfecal bacteria and their differential resistance to chlorination, more accurate approaches involving the fecal coliform and fecal *Streptococci* groups are required.

Pesticides

Pesticides are most commonly used in agricultural applications for the control of weeds and pest organisms. The presence of these substances in water is troublesome because they are toxic to most aquatic organisms and many are known or suspected carcinogens. Potential impairments from pesticides include damage to aquatic fauna and concerns for human health (contamination of domestic water supply or fishery). Concentration levels rather than overall loadings are most important. Contamination of groundwater by organic chemicals can occur through leaching.

Metals

Heavy metals are a group of elemental pollutants including arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Industries such as electroplating, battery manufacturing, mining, smelting, and refining have been identified as potential sources of heavy metals. Metals may enter surface waters either dissolved in runoff or attached to sediment or organic materials. Metals can also enter groundwater through soil infiltration.

Metals can have toxic effects on humans, fish, wildlife, and microorganisms. Since metals do not readily decay, their persistence in the environment is a problem potentially contributing to long-term habitat and public water supply degradation. A principal concern about metals in surface water is their entry into the food chain at relatively low concentrations and their bioaccumulation over time to toxic levels. High concentrations of arsenic can cause dermal and nervous system toxicity effects; high concentrations of cadmium can cause kidney effects; and high concentrations of chromium have been linked to liver and kidney effects. Lead can result in central nervous system damage and kidney effects and is also highly toxic to infants and pregnant women. High concentrations of mercury can cause central nervous system disorders and kidney effects; high concentrations of selenium have gastrointestinal effects; and high concentrations of silver can cause skin discoloration.

Other toxic chemicals

Thousands of industrial and petroleum processing chemicals such as plasticizers, solvents, waxes, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) make up the final group of toxic substances. Alkyl phthalates, chlorinated benzenes, PCBs, and PAHs are broad subcategories in this group. Some chemicals are carcinogenic directly to humans, while others affect fish, aquatic organisms, or plants within the water column or in the benthic sediment layer.

Biological conditions

Because water quality problems often manifest themselves in terms of fish or organism health, many states and the EPA are promoting data collection on fish and benthic organism communities while conducting water quality assessments. While biological data are generally considered to be indicators of water quality rather than specific parameters, it may be cost-effective to compile this data and water quality data simultaneously. The biological data may be critical in associating pollutant concentrations with long-term detrimental effects. However, a great deal of uncertainty exists when interpreting this type of data.

Assemble water quality data

Assemble all of the relevant water quality data available for the watershed. It is very important to keep the assessment objectives in mind to keep the team focused. Try to avoid collecting information outside the scope of the project.

Identify data deficiencies

Problems exist when comparing data sets collected by different entities. For example, the data may have been collected using different methodologies and QA/QC protocols or at different times and locations. To facilitate the combination of data from various sources, team members will need to become familiar with the designation of stream segments and waterbodies within their watershed.

An important part of creating the database will be judging the validity of the data. Laboratory errors, data translation errors, improper chain of custody procedures, and several other independent sources of error can affect results. Undoubtedly, data interpretations will need to be made, but they should be made carefully by experienced professionals.

Step 4. Identify water quality standards and criteria

Identify existing water quality standards and criteria applicable to the waterbodies and stream segments being assessed. Water quality standards are laws or regulations adopted by states and tribes to enhance water quality and to protect public health and welfare. Water quality standards provide the foundation for accomplishing two of the principal goals of the CWA: 1) to restore and maintain the chemical, physical, and biological integrity of the nation's waters, and 2) where attainable, to achieve water quality that promotes protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water (EPA 1999).

A water quality standard consists of three elements: 1) the designated beneficial use or uses of a waterbody or segment of a waterbody, 2) the water quality criteria necessary to protect the use or uses of that particular waterbody, and 3) an antidegradation policy. Water quality criteria describe the quality of water that will support a designated use and may be expressed as either quantitative limits or a qualitative description. In practice, criteria are set at levels that will protect the most sensitive of uses, such as human health or aquatic life. An antidegradation policy ensures that water quality improvements are conserved, maintained, and protected (EPA 1999).

Water quality criteria can be obtained from a wide range of sources:

- EPA criteria.
- State water quality criteria.

- Site-specific criteria based on scientific studies.
- Agency guidelines.

Table 7 is an example of EPA water quality criteria. The term biota is fairly comprehensive, so there may be scientifically justifiable reasons for requiring more or less stringent criteria for a particular species than those shown in the table. Table 8 provides regional reference values for natural water quality derived from 57 stations constituting the National Hydrologic Benchmark Network.

Not all criteria have been translated into state or local laws; however, some agencies develop policy based on criteria. A tribe or local health department, for example, may regulate beach closures based on fecal coliform criteria without a specific water quality standard.

Table 7. EPA water quality criteria for DO concentrations (mg/L)

	Cold water biota		Warm water biota	
Period	Early Life Stages	Other Life Stages	Early Life Stages	Other Life Stages
30-day mean	NA	6.5	NA	5.5
7-day mean	9.6 (6.5)*	NA	6.0	NA
7-day minimum	NA	5.0	NA	4.0
1-day minimum	8.0 (5.0)	4.0	5.0	3.0

* Applies to species that have early life stages exposed directly to water column.

Novotny and Olem (1994)

Table 8. Regional reference values for regional natural water quality

	Region				
Parameter	Eastern	Midwest	Great Plains	Mountain	Pacific
TSS (mg/L)	5-10	10-50	20-100	5-20	2-5
BOD (mg/L)	1.0	1-3	2-3	1-2	1
Nitrate (mg/L)	0.05-0.2	0.2-0.5	0.2-0.5	0.1	0.05-0.1
Total Phosphorus (mg/L)	0.01-0.02	0.02-0.1	0.1-0.2	0.05	0.05-0.1
Total coliforms (MPN/100 ml)	100-1000	1000-2000	500-2000	100	100-500

Novotny and Olem (1994)

Step 5. Identify indicators of impairment

Water quality impairment is typically defined as the exceedence of criteria, but other indicators of problems, such as fish kills, algae blooms, and localized epidemics, should also be examined. For each waterbody or stream segment, record potential indicators of impairment on Form WQ1.

Numerous studies have been conducted to determine the precise combination of water quality indicators necessary to accurately assess watershed conditions (EPA and USFWS 1984, Heaney 1989, Greeley-Polhemus Group 1991). Snodgrass et al. (1993) present a sub-basin framework for managing environmental quality where flooding, erosion, surface water quality, groundwater (quality and quantity), natural features (wetlands), aquatic communities, recreation, aesthetics (water, valleyland), terrestrial (wildlife, woodlots), and receiving waterbody issues are examined. Each category could be further divided to coincide with the available data if additional clarification were needed. The EPA (1996a) identified 18 environmental water quality indicators to meet five national environmental goals. These indicators reflect the requirements of both the CWA and the Safe Drinking Water Act. However, many of the indicators comprise multiple parameters whose relative significance has yet to be established.

The EPA (1995a) used environmental indicators to judge the effectiveness of stormwater management efforts. The indicators were selected from categories such as 1) water quality, 2) physical and hydrological, 3) biological, 4) whole watershed, 5) social, 6) programmatic, and 7) site-specific compliance. Unfortunately, monitoring many of these indicators would be cost-prohibitive.

Biological indicators have received considerable attention in recent years as potential markers of watershed health. However, interpreting the results of bioassessment studies can be difficult. Organism populations and community structures can vary considerably according to season and site, making it difficult to interpret fluctuations.

Step 6. Analyze water quality data

Analyze the water quality data obtained in Step 1 and compare the data with the standards and criteria identified in Step 2 to assess whether the existing water quality can support the beneficial and cultural uses identified in Step 3. In some cases, evaluation of exceedences may only require comparison of monitoring data to established standards and criteria. In more complicated watersheds, the assessment team might have to evaluate the quality of the data, perform statistical analyses, or suggest possible standards or criteria. The major tasks of this step are illustrated in Figure 2. The key questions listed in Box 2 will help guide the Water Quality assessment team during the data analysis phase.

Figure 2.
Major tasks in water quality data analysis

Prioritize waterbodies and stream segments
↓
Determine locations and frequencies of exceedence
↓
Compare water quality data with reference conditions
↓
Evaluate indicators of water quality conditions
↓
Summarize water quality problems

Level 1 assessment involves basic statistical analyses to describe the central tendency and spread of water quality data. The mean or median describes the central tendency of the sample, while the standard deviation or interquartile range measures the spread of data from the mean. Analysts can refer to several documents for more detailed descriptions of statistical procedures (Gilbert 1987, MacDonald et al. 1991, EPA 1997a).

Prioritize waterbodies and stream segments
Decide which waterbodies or stream segments require more detailed water quality evaluations. Contact other members of the assessment team, such as the Aquatic Life or Channel analyst to identify critical areas. Reports that summarize water quality data and concerns, such as the state 305(b) reports, can also help to focus the assessment.

Aquatic Life
Channel

Box 2. Key questions for water quality data analysis

- In what sequence should the waterbodies be analyzed?
- How were the standards set up, (e.g., based on monthly or weekly mean concentration)?
- Is the water quality data format consistent with the standard?
- What water quality parameters have not met the standard and for how long?
- What beneficial uses are not supported in the waterbody?
- What are relevant background or reference conditions for the waterbodies of interest?
- How different is the existing water quality from the reference conditions?

Determine locations and frequencies of exceedences

Review water quality data to identify exceedences of water quality criteria. Water quality problems can also be identified by referencing water quality–related information such as reports on fish kills, state 303(d) reports, and other reported violations of water quality standards.

The strength and rigor of the quality control should be considered in determining whether or not the exceedence data are conclusive. EPA standards for monitoring should be considered in reviewing the information (EPA 1996b). If monitoring data are inconclusive or suspect because of quality control, care should be exercised in inferring water quality problems.

Compare water quality data with reference conditions

Community Resources
Historical Conditions

Another approach for confirming water quality problems is to compare water quality data to reference conditions, which represent the natural state prior to significant human disturbance. Reference conditions can be identified in watershed areas with minimal human influence. Another option is to use historical data to identify past reference conditions. Data on reference conditions can be extremely valuable in the analysis process to determine the degree of watershed deterioration and the feasibility of maintaining certain beneficial uses. The reference condition approach is particularly useful when water quality standards are not available.

Evaluate indicators of water quality conditions

Community Resources

Using the information on indicators of water quality collected in Step 5, consider whether water quality standards and criteria are sufficient to protect community resources. Identify waterbodies where qualitative indicators such as fish kills, "swimmer's itch," unpleasant odors, or fish consumption advisories suggest impairment of community resources. Consult with the Community Resources analyst to help incorporate observations from the local community.

Aquatic Life

Biological monitoring programs may provide useful information for identifying habitat alterations, the cumulative effects of pollutants, and the biological integrity of aquatic communities. A change in the abundance of organisms or in community composition may indicate problems not revealed by more conventional water chemistry monitoring. Consult with the Aquatic Life analyst about the status and trends of aquatic populations.

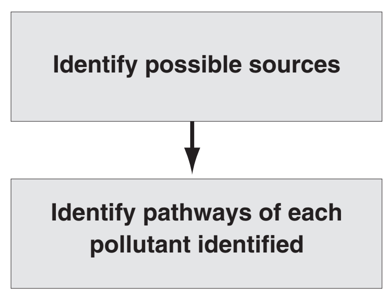
Summarize water quality problems
Summarize the water quality problems in Form WQ1 and the Water Quality report. The analysis of water quality exceedences, reference conditions, and impairment indicators should provide the evidence to document water quality problems. Impaired stream segments or other waterbodies should be highlighted on Map WQ1.

Water quality data may not be available or may have significant gaps for many of the parameters. Major gaps in water quality data (e.g., inadequate coverage, infrequent measurements, lack of reliability) should be identified in the Water Quality report. Insufficient standards or criteria to evaluate water quality should also be highlighted.

Step 7. Identify potential pollution sources

Identify the potential sources of the water quality problems found in the watershed. The information can be used as either a basis for further assessment or as a reference for management plans. The general tasks involved in this step are illustrated in Figure 3. Box 3 lists key questions that should be considered during this step. Concluding that a waterbody is at risk from a particular practice often requires explicit evaluation of the hazardous inputs, the transport of pollutants, and delivery to sensitive resources in a Level 2 assessment.

Figure 3. Major tasks in pollution source identification



Box 3. Key questions for pollution source identification

- What are the potential sources of sediment, water, heat, chemicals, pathogens, nutrients, etc.?
- What is the fate of pollutants upon entry to the stream?
- What is the potential for chemical change, dilution or other transformation effects?
- What is the potential for delivery via runoff, infiltration, or atmospheric transport to sensitive segments?
- What is the evidence for cause-and-effect linkages?

Identify possible sources
Develop a list of all possible sources that relate to the water quality impairment, including both point sources and non-point sources. A number of resources may be useful in this part of assessment:

- **Resource Conservation and Recovery Act (RCRA) site data**. Under the RCRA, the EPA evaluates hazardous waste sites for corrective action. Information may be available on toxic sources and risks to resources.

- **NPDES permit data**. State agencies are commonly responsible for implementation of point source discharge permitting under the CWA. Under this authority, states provide permits to pollutant dischargers based upon a review of receiving water assimilation capacity, loading, and other considerations.

- **Stormwater evaluations**. County and city governments commonly conduct analyses of stormwater and associated effects on water quality. This information may indicate pollutant loadings of toxic and non-toxic substances.

- **Health department studies and sanitary surveys**. Health departments (state and county level) commonly evaluate water quality impacts, including the impacts on shellfish beds, groundwater, and surface water.

- **State recreational studies**. State recreation agencies commonly evaluate site qualities with respect to human use potential, as well as the condition of fish and wildlife habitat.

- **Species evaluations by the USFWS and state resource agencies**. Habitat conservation plans and other analyses evaluating habitat and impacting land practices may be on file.

- **Section 319 studies (under the CWA)**. These may include evaluations of water quality problems, inventories, etc.

- **Resource agency studies**. Local, state, and federal agencies that regulate land disturbing activities often have information on land use and potential water quality problems. The NRCS commonly funds conservation districts to evaluate water quality problems specific to agricultural lands. The BLM and USFS often have data on timber sales, grazing allotments, and mining claims that may impact water quality.

Identify pathways of each pollutant identified

Identify the relationship between pollution sources and the water quality problems. A pathway diagram is a useful tool to show the potential links between the source of generation and water quality (Figures 4 - 8 in the "Level 2 Assessment" section). The diagram is a simple way to crystallize the strategy for the assessment and narrow it down to manageable dimensions.

The identification of pathways should be based upon knowledge of pollutant-generating activities, the transport of pollutants, and the location of water quality problems. The Level 2 assessment provides more detailed information on identifying pollutant pathways.

Step 8. Produce Water Quality report

The Water Quality report should summarize water quality conditions, indicators of impairment, and connections between pollutant sources and resource impairment. Highlighting assumptions, gaps in data, and scientific uncertainty in the Water Quality report will be important to evaluate the confidence in the assessment.

The report will typically include the following components:

- Summary of available water quality data.
- Applicable water quality standards and criteria.
- Community resources dependent on water quality.
- Exceedences of criteria and standards.
- Indicators of impairment.
- Potential sources of impairment.
- Conclusions of the assessment.
- Future monitoring and research needs.
- Confidence in the assessment.

Level 2 Assessment

This section provides a general overview of methods and tools that can be used in a Level 2 Water Quality assessment. It is not comprehensive and by no means represents a complete procedure. Sources that provide more detailed information on assessment methods are noted throughout this section.

Level 2 assessment can be complicated by the fact that water quality parameters are often interrelated. Unlike more visible indicators of watershed health, water quality problems often manifest themselves through symptoms that may occur miles downstream of the actual problem. For example, eutrophication problems, caused by excessive phytoplankton growth, require sufficient nutrients, temperature, light, and time. Problems with excessive nutrient inputs upstream may not become evident until after water flows into a lake, where sediments settle, allowing additional light penetration, the water temperature increases, and the algae has time to grow. Investigating the lake for the source of nutrients may prove to be futile because they were transported from upstream sources. This complexity may make characterization or identification of water quality problems very difficult.

Level 2 assessment for water quality can be quite complicated and requires interaction with several of the other module analysts, patricularly the Hydrology, Aquatic Life, and Erosion analysts. Pathway analysis requires knowledge of water chemistry and environmental science. Use of complicated mathematical models requires knowledge of both water quality and computer modeling, and extensive training and experience may be necessary to use computer simulation packages. In addition, Level 2 assessment may require extensive field data collection at specific locations throughout the watershed. Thus, estimates of the time and resources required for assessment need to take into account these elements.

This section focuses on methods and quantitative tools for estimating pollutant loading from various sources. The methods and tools are divided into four categories:

- Analysis of mixing and dilution.
- Loading tables.
- Parameter-specific pathway analysis.
- Computer simulations.

Analysis of Mixing and Dilution

A mixing and dilution calculation is the most widely used method for evaluating the impact of a pollutant discharge on a receiving waterbody. The pollutant from a particular source is typically diluted after being discharged. The impact of the discharge can be evaluated by determining the pollutant concentration in the receiving waterbody after mixing. Conversely, if an elevated pollutant concentration is measured and a source can be identified, then the amount of discharge from the source can be back-calculated. The equation used for these purposes is as follows:

$$C_f = (C_1Q_1+C_2Q_2)/(Q_1+Q_2)$$

Where: C_f = pollutant concentration after mixing.
C_1 and C_2 = pollutant concentrations in the source and the receiving water before mixing, respectively.
Q_1 and Q_2 = flow rates of the source and the receiving water, respectively.

For a lake or a pond without appreciable water exchange, the mixing equation can be written as follows:

$$C_f = (C_1V_1+C_2V_2)/(V_1+V_2)$$

Where: V_1 and V_2 = volumes of the source and the receiving water, respectively.

The resulting pollutant concentration assumes complete mixing of the pollutant and the receiving waterbody. This generally will not occur until some distance downstream. Within the initial dilution zone, concentrations may be considerably higher. The length of the mixing zone can be quite variable depending on stream characteristics and possible density or thermal stratification between the pollutant and the natural stream. Several methods for determining the mixing zone length can be found in the literature. These range from relatively simple rule-of-thumb approaches to computer models such as CORMIX. Analytical solutions can be found for river mixing in references such as Thomann and Mueller (1987) and Martin and McCutcheon (1999). Martin and McCutcheon (1999) also present more in-depth theoretical discussions concerning mixing in streams and lakes.

Loading Tables

When detailed information is not available or time and resources are not adequate to do modeling, proper use of loading tables allows quick estimations of pollutants from a particular source or land use. Loading tables give unit pollutant loading rates. Examples include soil erosion per acre of land, atmospheric deposition per square foot of surface area, and solids product rate per foot of curb length in cities. Table 9 illustrates some approximate loading rates for different land uses in Washington State. Other sources for unit loading values include McElroy et al. (1976), Thomann and Mueller (1987), and Chandler (1993). Novotny and Chesters (1981) include approximations for nutrient export based on geographic regions of the United States and land use. The values are given in terms of concentration, so approximations for runoff must also be made independently.

Hydrology

Table 9. Unit loads of pollutants (kg/ha/yr) from different land uses*

Pollutant	Central business district	Other commercial	Industrial	Single family res.	Multi-family res.	Cropland	Pasture	Forest	Open
TSS	1080	840	56	17	440	450	340	85	7
COD	1070	1020	63	28	330	n.a.	n.a.	n.a.	2.0
Pb	7.1	3.0	2.0 - 7.1	0.1	0.7	0.005 - 0.006	0.003 - 0.015	0.01 - 0.03	n.a.
Zn	3.0	3.3	3.5 - 12	0.22	0.33	0.03 - 0.08	0.02 - 0.17	0.01 - 0.03	n.a.
Cu	2.1	n.a.	0.33 - 1.1	0.03	0.33	0.01 - 0.06	0.02 - 0.04	0.02 - 0.03	n.a.
NO_3+$N0_2$-N	4.5	0.67	0.45	0.33	3.8	7.9	0.33	0.56	0.33
TKN	15	15	2.2 - 15	1.1 - 5.6	3.4 - 4.5	1.7	0.67	2.9	1.7
TP	2.8	2.7	0.9 - 4.0	0.2 - 1.5	1.3 - 1.6	0.1 - 3.0	0.07 - 3.0	0.02 - 0.45	0.06

* Exact values are given where available; otherwise ranges are reported.

Adapted from Horner et al. (1986)

Parameter-Specific Pathway Analysis

Many equations or methods have been developed to analyze the relationship between different forms or phases of pollutants. Pathway analysis explores the relationship between different forms of a pollutant based on the physical or chemical processes of transformation. Knowledge of these relationships will improve identification and evaluation of pollutant sources. The pathway analysis conducted in a Level 1 assessment (Step 7) is often qualitative, aiming at source identification. Pathway analysis conducted in a Level 2 assessment is more quantitative, aiming at identification of the degree of impact from one or more possible sources.

Temperature

The relationship between water temperature and the factors controlling it is well understood and amenable to quantitative prediction. The temperature of a waterbody can be determined by calculating the heat balance between the waterbody and the surrounding environment. Major controlling factors include solar radiation, geographical location, elevation, groundwater interaction, shading, and seasonal weather conditions such as rain and wind.

Land use activities that affect discharge, streamside vegetation cover, and channel morphology all exert variable influences on temperature in different climates. With other factors held constant, streams with lower discharge are more susceptible to temperature increases during the summer and decreases during the winter. Reduction of base flows also causes increased seasonal temperature extremes because groundwater commonly warms streams in winter and cools them in summer.

◀ Hydrology

The reduction of stream surface shading by the removal of riparian vegetation can significantly affect temperature, depending upon elevation, stream hydrology, and groundwater/surface water interaction. Riparian grazing can also aggravate seasonal water temperature extremes by reducing base flows via channel incision or soil compaction. Restoration of riparian soils and vegetation through improved range management is one of the most effective management tools available for increasing summer base flows.

◀ Erosion

Increases in channel width caused by high levels of sediment delivery or loss of bank stability also exacerbate water temperature extremes in winter and summer. In summer, Channel Erosion

vegetation of a given height is less effective in shading wider channels. Wider and shallower channels also have a greater heat load under a fixed energy budget because of the increase in the stream surface area.

Temperature modeling can be conducted in two ways. The first deals with mixing of water that has different temperatures, and the second is based on the heat balance of a control waterbody. The mixing equation presented in the "Analysis of Mixing and Dilution" section, can be used in temperature calculations by substituting temperature (T) for concentration (C). This approach is generally used to estimate temperature impacts from point sources. The heat balance approach, on the other hand, is used widely in computer modeling for evaluating non-point sources. A good example can be found in the QUAL2E user's guide (EPA 1995b).

Total suspended solids (TSS)

Erosion

The major sources of TSS include sediment, algae growth in the waterbodies, and point source discharges. The sediment resulting from agricultural and urban runoff and from streambanks can be estimated using methods provided in the Erosion module. TSS caused by algae growth can be related to the nutrient concentration and productivity of the waterbody. Direct discharge from point sources can be estimated from the NPDES permit data, which are maintained by state agencies. TSS in a waterbody is additive; the concentration of the TSS in a waterbody is the summation of the mass of TSS from different sources divided by the volume of the waterbody. Some portion of the suspended solids will settle.

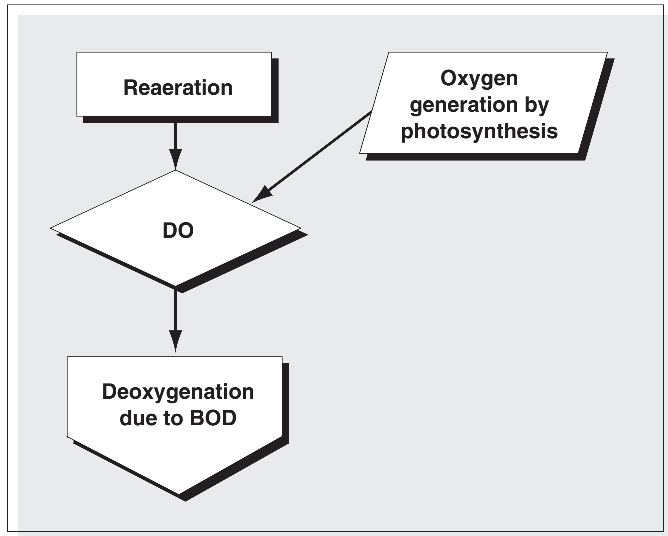
Dissolved oxygen (DO)

The major DO sources include photosynthesis and reaeration (Figure 4). Cool temperature, rapid aeration, and relatively low biochemical oxygen demand (BOD) may increase DO. Respiration of photosynthetic organisms, decay of organic matter in the water column, and benthic oxygen demand decrease DO. Introduction of organic matter from both point and non-point sources to streams can increase BOD and decrease DO. Photosynthetic contributions of oxygen occur only during daylight hours and are quite seasonal. The primary contributors are algae. Highly eutrophic waters may range in DO concentration from supersaturated during hot, sunny days to anaerobic at night.

In mountainous environments, streams possess little vulnerability to low DO because fine organic debris is generally sparse and reaeration of flowing water is more than sufficient to maintain high levels of DO. Low DO is more likely when the following conditions are present:

- Very slow-moving, low-gradient, warm streams with low discharge (i.e., low reaeration rates).
- Heavy inputs of fine organic debris to low-flow streams, causing a large BOD or high concentrations of organics.
- Warm, eutrophic streams, where high rates of photosynthesis and respiration cause diurnal fluctuations in DO (consuming oxygen without reaeration). These conditions are similar to those associated with lake eutrophication.

Figure 4. A simplified pathway of DO



Large BOD is quite often localized to short reaches where organic material accumulates. A second source of BOD demand is the growth of attached organisms, such as the filamentous bacteria often released in wastewater discharges.

In general, risk determination should be based on high organic loading to slow moving streams with limited reaeration potential. Streams subject to warming as a result of low natural flow, water withdrawals, and loss of riparian shade are especially susceptible.

The saturation potential of oxygen depends on the water temperature, the atmospheric pressure, and the salinity. For fresh water at sea level, the DO saturation concentration in mg/L can be expressed as a function of temperature (American Public Health Association 1985):

$$C_s = -139.34411 + \frac{1.575701\ \mathrm{E}5}{T} - \frac{6.652308\ \mathrm{E}7}{T^2} + \frac{1.2438\ \mathrm{E}10}{T^3} - \frac{8.621949\ \mathrm{E}11}{T^4}$$

Where: T = temperature in degrees Kelvin (°C + 273.15).
C_s = DO saturation (mg/L)

Degradation of pollutants often reduces the DO concentration below the saturation value. The oxidation of carbonaceous substances often causes reduced oxygen levels downstream of point sources. Municipal waste increases BOD, so wastewater treatment plants are a common starting point for this type of analysis. A common tool for predicting DO concentrations under various flow conditions is the Streeter-Phelps Equation. This equation is essentially a balance between DO consumption due to BOD expression and stream reaeration. According to Thomann and Mueller (1987), the DO balance equation can be written as follows:

$$c = c_s - \left\{ \frac{K_d}{K_a - K_r} \left[\exp(-K_r \frac{x}{U} - \exp(-K_a \frac{x}{U} \right] \right\} L_o - (c_s - c_o) \exp(-K_a \frac{x}{U})$$

Where: K_a = reaeration coefficient.
K_d = effective deoxygenation rate.
K_r = BOD loss rate.
x = distance downstream of point source.
U = average water column velocity.
L_o = BOD concentration at the outfall.
c_o = DO concentration at the outfall.
c_s = saturation concentration of oxygen.

pH

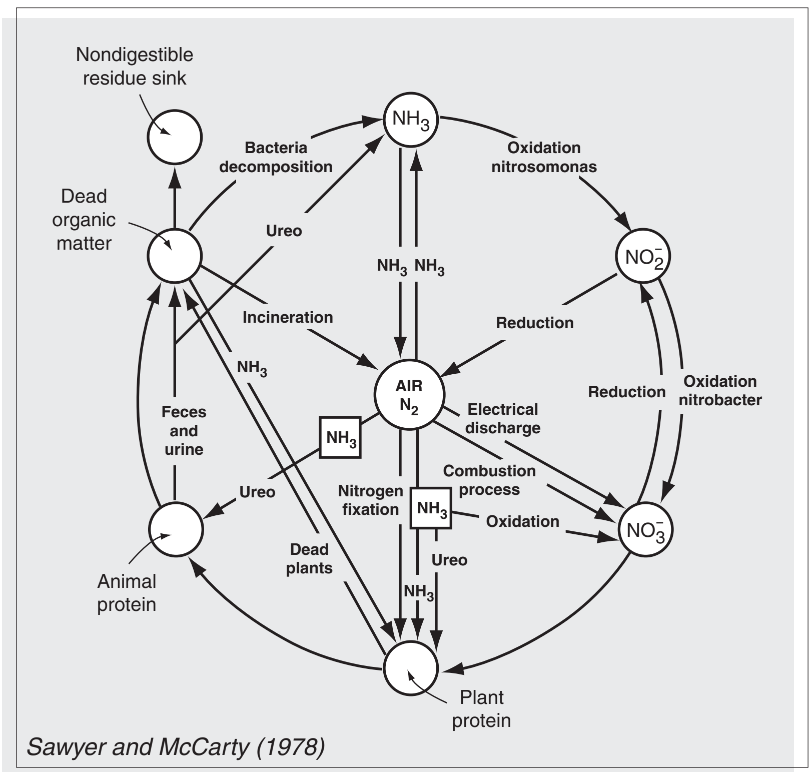
pH modeling involves describing the hydrogen ion balance in water. The natural pH balance of a waterbody can be affected by industrial effluents and atmospheric deposition of acid-forming substances (i.e., acid rain). Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded. Daily variations in pH can be caused by photosynthesis and the respiration cycle of algae in eutrophic water. The rapid growth of algae on a clear day can consume a significant amount of carbon dioxide from the water and increase the pH. During the night, however, the respiration of algae produces excessive carbon dioxide, which lowers the pH.

Nitrogen

In a natural environment, nitrogen undergoes biological and non-biological transformations according to the nitrogen cycle (Figure 5). The major non-biological processes involve phase transformations such as volatilization, adsorption, and sedimentation. The biological transformation involves the following:

1. Uptake of ammonia and nitrate by plants and micro-organisms to form organic nitrogen.
2. Fixation of nitrogen gas by plants and bacteria to produce organic nitrogen.
3. Ammonification of organic nitrogen to produce ammonia during decomposition of organic matter.
4. Oxidation of ammonia to nitrite and nitrate under aerobic conditions.
5. Bacterial reduction of nitrate to nitrous oxide and molecular nitrogen under anaerobic conditions through denitrification.

Figure 5. Nitrogen cycle



Ammonia is highly soluble in water and occurs naturally in waterbodies from the breakdown of nitrogenous organics. Discharges from industrial and municipal wastewater treatment facilities are the most common non-natural sources of ammonia. Ammonia can also result from atmospheric deposition.

In aqueous solution, ammonia occurs in two forms, the un-ionized form (NH_3) and the ionized form (NH_4). The un-ionized form of ammonia is toxic to aquatic life. The ionized ammonia can be adsorbed onto colloidal particles, suspended sediments, and bed sediments. Most reports refer to the concentration of total ammonia nitrogen, which is the summation of the two forms:

$$NH_3 + NH_4 = \text{Total Ammonia Nitrogen}$$

The equilibrium between the two forms is determined by pH; the higher the pH, the more un-ionized ammonia and the higher the toxicity. Unpolluted waters generally contain a small amount of ammonia, usually < 0.1 mg/L as nitrogen. Total ammonia concentrations measured in surface waters are typically less than 0.2 mg/L but may reach 2-3 mg/L. A higher concentration could be an indication of organic pollution such as domestic sewage, industrial waste, or fertilizer runoff. Natural seasonal fluctuations also occur as a result of the death and decay of aquatic organisms, particularly phytoplankton and bacteria in nutritionally rich waters. High ammonia concentrations may also be found in the bottom of lakes that have become anoxic.

Nitrate is an essential nutrient for aquatic plants, and seasonal fluctuations can be caused by plant growth and decay. Under aerobic conditions, ammonia can be biologically oxidized to nitrite and then to nitrate by a group of bacteria called nitrifiers. Under anaerobic conditions with the presence of organic carbon, nitrate can also be reduced to nitrite and then to nitrogen gas. As nitrite is an intermediate product, nitrite concentration in natural waterbodies is usually quite low. Natural sources of nitrate to surface water include igneous rocks and plant and animal debris. Natural concentrations, which seldom exceed 0.1 mg/L, may be increased by municipal and industrial wastewaters, including leachates from waste disposal sites and sanitary landfills. In rural and suburban areas, the use of inorganic nitrate fertilizers can be a significant source. Concentrations in excess of 5 mg/L usually indicate pollution by human and animal waste or fertilizer runoff.

Nitrate is very mobile in soil because of its negative charge. The leaching of nitrate to groundwater can cause groundwater impairments. Increasing groundwater nitrate concentrations in many agricultural regions have been attributed to fertilizer application and animal waste.

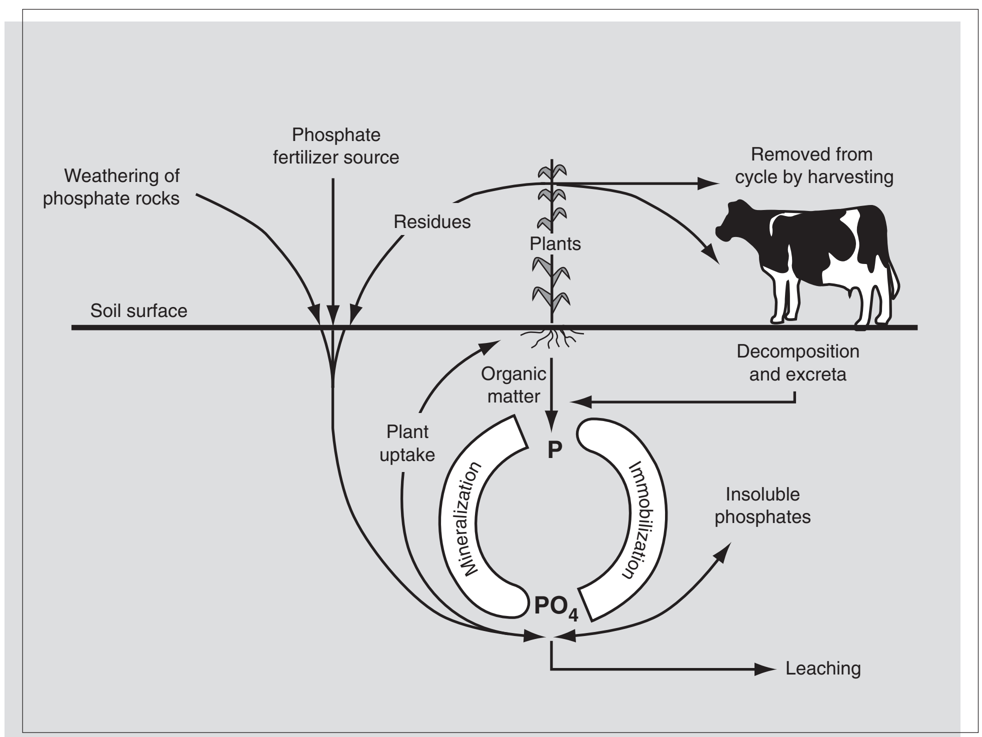
Surface water impairments from nitrogen include eutrophication and toxicity from nitrites, nitrates, and ammonia. Nitrites and ammonia are directly toxic to fish while nitrates and phosphates affect fish indirectly. High nitrate and phosphate concentrations are associated with stream eutrophication. Algae blooms and the profusion of other aquatic plants may directly kill fish when vegetation dies and deoxygenation occurs. Blooms and massive growth of other aquatic plants are possible when nitrate content in the presence of other essential nutrients exceeds 0.5 mg/L.

Most nitrogen transformation processes are evaluated using computer models because of the complexity of the nitrogen cycle caused by the many interactions. The computer simulation models are summarized in a later section.

Phosphorus

Natural sources of phosphorus are mainly derived from the weathering of phosphorus-bearing rocks and the decomposition of organic matter. Domestic wastewater (particularly wastewater containing detergents), industrial effluents, and fertilizer runoff contribute to elevated levels in surface waters. Major pathways of phosphorus transformation include plant uptake, fertilization, and residue decomposition (Figure 6). Unlike nitrogen, phosphorus is not particularly mobile in soils, and phosphate ions do not leach readily. Phosphorus is held tightly by a complex union with clay and soil particulates and organic matter. Most phosphorus is removed from soils either by crop uptake or by soil erosion.

Figure 6. Phosphorus cycle



Phosphorus is rarely found in high concentrations in fresh water as it is actively uptaken by plants. As a result, there can be considerable seasonal fluctuations in surface water concentrations. In most natural surface waters, phosphorus concentrations range from 0.005 to 0.020 mg/L. Concentrations as high as 200 mg/L can be found in some enclosed saline waters (Chapman 1996).

Most phosphorus-related water resource problems result from excessive annual loading. However, if the water resource flushes seasonally, only the phosphorus loading immediately preceding algae bloom periods may be of concern. For instance, runoff from row cropland or suburban developments may be the major phosphorus loading source on an annual basis, but these may be less important than wastewater treatment plant contributions to algae bloom conditions during the summer and early fall.

Phytoplankton growth can be simulated using the following equation:

$$G = G_{max} \frac{x}{K_s + x}$$

Where: G = growth rate based on nutrient limitation.
G_{max} = temperature corrected maximum growth rate.
x = nutrient concentration.
K_S = half saturation constant for nutrient-limited growth.

Pathogens

Bacteria and viruses originate from runoff from livestock areas (Edwards et al. 1997), bottom sediments (Sherer et al. 1988), wildlife (Weiskel et al. 1996), bacterial populations resident in the soil (Crane et al. 1983), septic systems (Weiskel et al. 1996), rural municipalities (Farrel-Poe et al. 1997), and runoff from urban areas (Schillinger and Gannon 1985). Pathogens are largely carried to waterbodies by runoff or sediment transport. Viruses depend heavily on adsorption to sediment particles, while bacteria may be transported to waterbodies by various mechanisms, including infiltration, surface runoff, and adsorption. Pathogens may enter separate storm sewers from leaking sanitary sewers, cross-connections with sanitary sewers, malfunctioning septic tanks, and animal wastes.

Tools used in water quality assessment for pathogens are models for predicting pathogen die-off and transport. Among the factors affecting survival of pathogens are pH, predation by soil microflora, temperature, presence of sediment, sunlight, and organic matter. Tables 10 and 11 present information on some factors that impact pathogen survival.

Table 10. Factors that affect survival of enteric bacteria and viruses in soil

Factor	Type of pathogen	Comments
pH	Bacteria	Shorter survival in acidic soils (pH 3-5) than in neutral and calcareous soils
	Viruses	Insufficient data
Predation by soil microflora	Bacteria	Increased survival in sterile soil
	Viruses	Insufficient data
Moisture content	Bacteria and viruses	Longer survival in moist soils and during periods of higher rainfall
Temperature	Bacteria and viruses	Longer survival at lower temperatures
Sunlight	Bacteria and viruses	Shorter survival at the soil surface
Organic matter	Bacteria and viruses	Longer survival or regrowth of bacteria when sufficient amounts of organic matter are present

EPA (1977) and Novotny and Olem (1994)

Pesticides

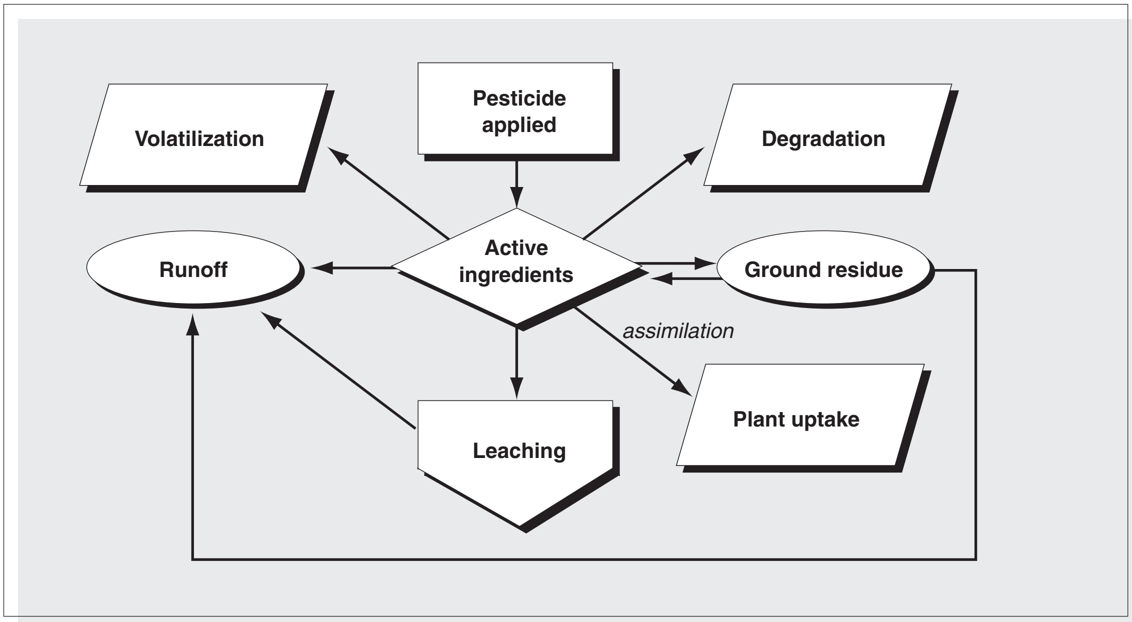
The major sources of pesticides and insecticides include agriculture, combined sewer outfalls, urban runoff, and runoff from rural residential areas. Insecticides include organochlorine, organophosphorus, and carbamate chemicals. Organochlorine compounds, such as DDT, dieldrin, aldrin, heptachlor, and lindane can persist in soils and aquatic environments for many years (Figure 7). For example, DDT has frequently been detected 10 years after its application.

Table 11. Survival of selected pathogens in soils

Organism	Survival time (in days)
Ascaris ova	up to 7
Entamoeba histolytica cysts	6-8
Enteroviruses	8
Hookworm larvae	42
Salmonella	15-100
Salmonella typhi	1-200
Tubercle bacilli	More than 200

Novotny and Olem (1994)

Figure 7. Pathways for pesticide and organic compound transformation and transport



Water quality–related pesticide modeling includes calculations and simulations of pesticide adsorption, decay, and transport. The oxygen status of soils and sediments has a pronounced effect on the microbial breakdown of organochlorine pesticides. In soils and sediments, DDT is rapidly converted to TDE (DDD) under anaerobic conditions. Several organochlorine pesticides, including heptachlor, lindane, and endrin, have been shown to degrade in soils to compounds of lower toxicity and reduced insecticidal activity. Herbicides are less ubiquitous than are organochlorine insecticides. Such compounds as s-triazines, picloram, monouron, and 2,4,5-T often persist in soils for as much as a year following application.

Downward movement of agriculturally applied chemicals into soil layers and groundwater is controlled by soil type, chemistry, pesticide composition, and climatic factors. The leachability of a compound from soils depends primarily on the degree of adsorption of the chemicals on soil particles. Models are also available to evaluate leaching potential (i.e., downward mobility) of organic chemicals. Further information on models to analyze pesticide movement are provided in the "Computer simulations" section.

Toxic metals and organic pollutants

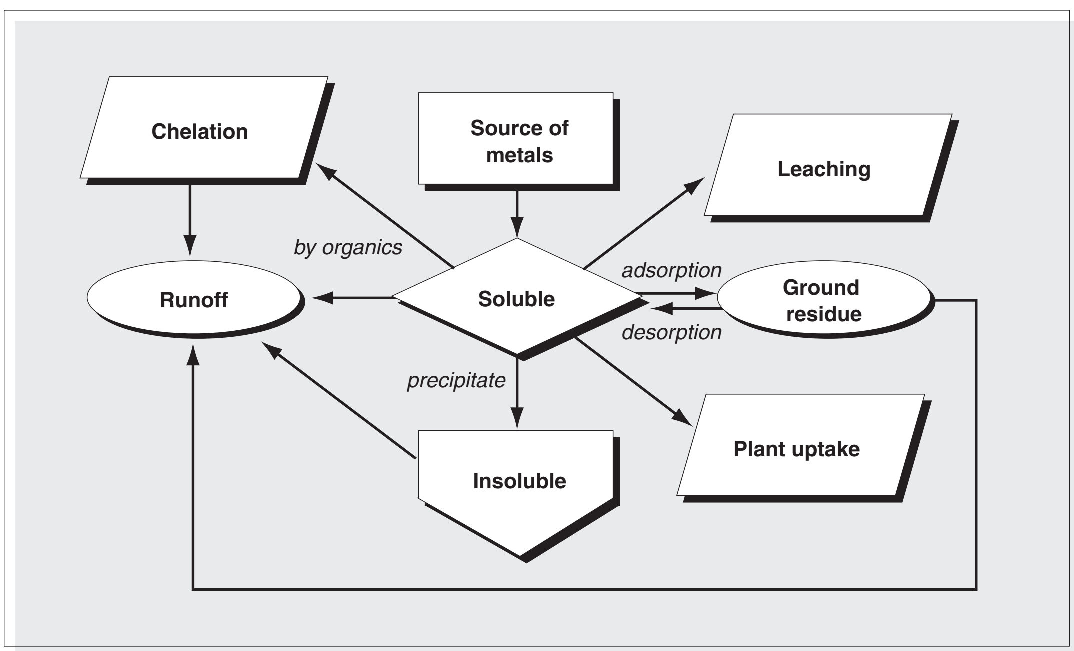
Toxic metals and organic pollutants can be a serious water quality problem within a watershed. While numerous sources exist for these pollutants (Table 12), most of

Table 12. Sources of toxic metals and organic pollutants

Pollutants	Sources
Arsenic	Natural geology, pesticide residue, industrial waste, smelting
Cadmium	Natural geology, mining, smelting
Lead	Lead pipes, lead-based solder
Mercury	Air and water discharge from paint, paper, and vinyl chloride producers, natural geology
Benzene	Petroleum fuel leaks, industrial chemical solvents, pharmaceuticals, pesticides, paints, and plastics
Carbon tetrachloride	Cleaning agents, industrial wastes from coolant manufacturers
p-dichlorobenzene	Insecticides, moth balls, air deodorizers
1,1-dichloroethylene	Plastic, dye, perfume, and paint manufacturers
1,1,1-trichloroethane	Food wrapping and synthetic fiber manufacturers
Trichloroethylene	Pesticide, paint, wax and varnish, paint stripper, and metal degreaser producers, dry cleaning wastes
Trihalomethanes	Surface water containing organic matter treated with chlorine

the toxic substances get into waterbodies and aquifers through point source discharges and stormwater runoff. Modeling the fate and transport of these substances requires knowledge of the chemical and physical characteristics of each particular substance (Figures 7 and 8). Computer simulation software packages are available for such applications.

Figure 8. Pathways for transformation and transport of heavy metals



Computer Simulations

Mathematical models for water quality assessment should be selected based on their intended uses and the conditions specific to the waterbody. A number of water quality models have been developed for general uses. The complexity of these models ranges from relatively simple spreadsheet-based pollutant loading models to extremely intricate, three-dimensional, finite-element models. Historically, many models focused on nutrients, DO, temperature, and BOD problems. Today, however, computer codes capable of handling metals and dissolved constituents are also being introduced. Tables 13 and 14 summarize the main features of several existing watershed simulation models that are generally available to the public. Detailed descriptions of these models can be obtained from other sources (EPA 1997b, Deliman et al. 1999). Tables 13 and 14 are not intended to be comprehensive and do not list models developed by private individuals or companies. Many of these models are proprietary or extremely expensive to purchase.

All water quality models are approximations of mathematical or empirical relationships. Consequently, it is very important that users understand the basic limitations or constraints introduced by the approximations. A great deal of expertise in running and interpreting model results is needed. Models can be shown to produce a widely varying range of outputs depending on the selection of coefficients and other assumptions. Proper calibration, validation, and sensitivity analysis require experience. The validity of the results may be drawn into question by inexperienced modelers. Used properly, models are powerful tools that can be used to help design water quality monitoring programs and evaluate remediation scenarios. However, improperly used models will ultimately lead to inconclusive or erroneous results and may cost more time and resources than they save.

Table 13. Capabilities of water quality models

Models	Source	Attributes										
									Range of applications			
		Temperature	Nutrients	Metals	Pesticides	Erosion Modeling	Steady-State (SS) or Dynamic (D)	In-stream Water Quality Simulation	Screening	Intermediate	Detailed	Management
AGNPS	USDA	N	Y	N	Y	Y	D	N				
ANSWERS	Purdue	N	Y	N	N	Y	D	N				
BATHTUB	USACE		Y	N	N	N	SS		H	M	-	M
CE-QUAL-RIV1	USACE	Y	Y	N	N	N	D	Y	H	H	H	H
CE-QUAL-W2	USACE	Y	Y	N	N	N	D	Y	L	H	H	H
CE-QUAL-ICM	USACE	Y	Y	Y	Y	N	D	Y	-	M	H	H
CH3D-WES	USACE	Y	N	N	N	N	D	Y	L	M	H	M
CREAMS	USDA		Y		Y	Y		N				
DELFT3D	DELFT	Y	Y	Y	Y	N	D	Y	L	M	H	H
DYNTOX	EPA						D		H	L	-	L
EFDC	Tetra Tech	Y	N	N	N	N	D	Y	L	M	H	M
EUTROMOD	NALMS		Y	N	N	N	SS		H	M	-	M
EXAMSII	EPA	N					SS		H	H	-	M
HSPF	EPA		Y		Y	Y	D	Y	L	M	H	H
PRZM	EPA		N		Y	Y		N				
QUAL2E	EPA	Y	Y	N	N	N	SS	Y	H	H	M	H
SWRRB	USDA		Y		Y	Y		N	M	H	H	M
SMPTOX	EPA	N	N	Y	Y	N	SS	Y	H	M	M	H
TPM	William & Mary	Y	Y	Y	N	N	SS	Y	H	H	M	H
UTM-TOX	ORNL		N		N	Y		N				
WASP5	EPA	N	Y	Y		N	D	Y	L	H	L	H
WEPP	USDA					Y						

H = High
L = Low
M = Medium

N = No
Y = Yes

EPA (1997b)

Table 14. Overview of water quality models

Watershed-scale loading models

Simple methods	*Mid-range methods*	*Detailed models*
EPA Screening	SITEMAP	STORM
Simple Method	GWLF	ANSWERS
Regression Method	Urban Catchment Model	DR3M-QUAL
SLOSS-PHOSPH	Automated Q-Illudas	SWRRMWQ
Watershed	AGNPS	SWMM
FHA Model	SLAMM	HSPF
Watershed Management Model		

Field-scale loading methods	*Integrated modeling systems*
CREAM/GLEAMS	PC-VIRGIS
Opus	WSTT
WEPP	LWMM
	GISPLM
	BASINS

Receiving water models

Hydrodynamic	*Steady-state water quality*	*Dynamic water quality*	*Mixing zone models*
RIVMOD-H	EPA Screening	DYNTOX	CORMIX
DYNHYD5	EUTROMOD	WASP5	PLUME
EFDC	PHOSMOD	CE-QUAL-RIVI	
CH3D-WES	BATHTUB	CE-QUAL-W2	
	QUAL2E	CE-QUAL-ICM	
	EXAMS II	HSPF	
	TOXMOD		
	SMPTOX3		
	Tidal Prism Model		
	DECAL		

EPA (1997b)

References

American Public Health Association. 1985. Standard methods for the examination of water and waste water, 16th edition. American Public Health Association, Washington, D.C.

Buffo, J. 1979. Water pollution control early warning system. Section 1, Non-point source loading estimates. Municipality of Metropolitan Seattle (METRO), Washington.

Chandler, R. D. 1993. Modeling and nonpoint source pollution loading estimates in surface water management. Thesis, M.S.E., University of Washington, Seattle.

Chapman, D. 1996. Water quality assessments: A guide to the use of biota, sediments, and water in environmental monitoring. E & FN Spon., New York, New York.

Crane, S. R., J. A. Moore, M. E. Grismer, and J. R. Miner. 1983. Bacterial pollution from agricultural sources: A review. Trans. ASAE 26:858-866, 872.

Deliman, P. N., R. H. Glick, and C. E. Ruiz. 1999. Review of watershed water quality models. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report W-99-1, Vicksburg, Mississippi.

Edwards, D. R., B. T. Larson, and T. T. Lim. 1997. Nutrient and bacteria content of runoff from simulated grazed pasture. Presented at the 1997 ASAE Annual Meeting, Paper No. 97-2055, St. Joseph, Michigan.

Farrell-Poe, K. L., A. Y. Ranjha, and S. Ramalingam. 1997. Bacterial contributions by rural municipalities in agricultural watersheds. Trans. ASAE 40(1):97-101.

Gilbert, R. O. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York, New York.

Greeley-Polhemus Group. 1991. Economic and environmental considerations for incremental cost analysis in mitigation planning. U.S. Army Corps of Engineers, Institute for Water Resources, IWR Report 91-R-1, Washington, D.C.

Heaney, J. P. 1989. Cost effectiveness and urban storm-water quality criteria. In: L. Roesner, B. Urbonas, and M. Sonnen (eds.). Design of urban runoff quality controls. ASCE, New York, New York.

Horner, R., B. W. Mar, L. E. Reinelt, J. S.. Richey, and J. M. Lee. 1986. Design of monitoring programs for determination of ecological change resulting from nonpoint source water pollution in Washington State. University of Washington, Department of Civil Engineering, Seattle, Washington.

MacDonald, L. H., A. W. Smart, and R. C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. U.S. Environmental Protection Agency, EPA-910/9-91-001, Washington, D.C.

Martin, J. L., and S. C. McCutcheon. 1999. Hydrodynamics and transport for water quality modeling. Lewis Publishers, Boca Raton, Florida.

McElroy, A. D., S. Y. Chiu, J. W. Nebgen, A. Aleti, and F. W. Bennett. 1976. Loading functions for assessment of water pollution from nonpoint sources. U.S. Environmental Protection Agency, Midwest Research Institute, EPA-600/2-76-151, Kansas City, Missouri.

Novotny, V., and G. Chesters. 1981. Handbook of nonpoint pollution. Van Nostrand Reinhold, New York, New York.

Novotny, V., and H. Olem. 1994. Water quality: Prevention, identification, and management of diffuse pollution. Van Nostrand Reinhold, New York, New York.

Puget Sound Water Quality Authority. 1986. Nonpoint source pollution. Puget Sound Water Quality Authority, Seattle, Washington.

Regional Interagency Executive Committee (RIEC) and Intergovernmental Advisory Committee (IAC). 1995. Ecosystem analysis at the watershed scale: federal guide for watershed analysis, version 2.2. Regional Ecosystem Office, Portland, Oregon.

Sawyer, C. N., and P. L. McCarty. 1978. Chemistry for environmental engineering. McGraw-Hill Book Company, New York, New York.

Schillinger, J. E., and J. J. Gannon. 1985. Bacterial adsorption and suspended particles in urban stormwater. Journal of the Water Pollution Control Federation 57(5):384-389.

Sherer, B. M., J. R. Miner, J. A. Moore, and J. C. Buckhouse. 1988. Resuspending organisms from a rangeland stream bottom. Trans. ASAE 31(4):1217-1222.

Snodgrass, W., D. E. Maunder, K. Schiefer, and K. C. Whistler. 1993. Tools for evaluating environmental quality, water quality and water quantity issues. In: W. James (ed.). New techniques for modeling the management of stormwater quality impacts. Lewis Publishers, Boca Raton, Florida.

Thomann, R. V., and J. A. Mueller. 1987. Principles of surface water quality modeling and control. Harper & Row, New York, New York.

U.S. Environmental Protection Agency (EPA). 1977. Stanley W. Zison. Water quality assessment: A screening method for nondesignated 208 areas. EPA, EPA-600/6-77/023, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1994. Water quality handbook. EPA, Office of Water, EPA-823-B-94-005a, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1995a. Environmental indicators to assess the effectiveness of municipal and industrial stormwater control programs. Draft. EPA, Office of Wastewater Management, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1995b. QUAL2E Windows interface user's guide. EPA, Office of Water, EPA-823-B-95-003, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1996a. Environmental indicators of water quality in the United States. EPA, Office of Water, EPA-841-R-96-002, EPA, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1996b. The volunteer monitor's guide to quality assurance project plans. EPA, EPA-841-B-96-003m, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1997a. Monitoring guidance for determining the effectiveness of nonpoint source control. EPA, Office of Water, EPA-841-B-96-004, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1997b. Compendium of tools for watershed assessment and TMDL development. EPA, EPA-841-B-97-006, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1999. Introduction to water quality standards. EPA, Office of Water, EPA-823-F-99-020, Washington, D.C.

U.S. Environmental Protection Agency (EPA) and U.S. Fish and Wildlife Service (USFWS). 1984. 1982 national fisheries survey. EPA and USFWS, Washington, D.C.

Weiskel, P. K., B. L. Howes, and G. R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. Environ. Sci. Technol. 30:1872-1881.

Form WQ1. Summary of water quality conditions

Sub-basin	Waterbody	Segment	Beneficial uses	Parameters of concern	Indicators of impairment	Notes (data sources, land use hazards)